EXPERIMENTAL STUDY OF THE SLOWLY VARYING WAVE EXCITING DRIFT FORCES ON A BODY OF SIMPLE GEOMETRY

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The paper presents an experimental investigation of the first and second order wave exciting forces on a vertical cylinder restrained from moving. The objectives are to enhance the understanding of the physics of slowly varying forces and also obtain data for validation of theoretical models. The experimental data includes linear exciting forces, steady drift forces and slowly varying second order forces on monochromatic and bi-chromatic waves. The tests were performed in three different water depths representing shallow and deep waters. The time records are analysed with a least squares method to identify the harmonic content of the forces. It is shown that the second order slowly varying wave drift forces can be identified experimentally with a good consistency.

1. INTRODUCTION

Second order wave forces are important for different types of fixed and floating structures. Within a frequency domain approach, these forces can be decomposed into three components namely: a steady force, a difference frequency component and a sum frequency component. The difference frequency second order forces result on the slowly varying wave drift forces in irregular seas, which are important, for example, for floating moored structures. Usually the mooring system is compliant with the first order wave exciting forces since the natural period of the floater plus mooring is large compared to the wave period. However, the slowly varying drift forces have longer periods therefore they may excite the floater and mooring system at their natural frequency, resulting in large horizontal motions of the floater and tensions on the mooring lines.

Although the subject of slowly varying drift forces has been well studied in the past from the theoretical and numerical point of view, for both single and multi body configurations, little experimental data is available. Experimental studies focusing on steady drift forces were conducted by several researchers for a single body (Huijsmans et al., 1988) or for multi body configuration (Kashiwagi et. Al, 2005). Regarding the slowly varying drift forces, some experimental work has been presented as well, but focusing mainly on irregular sea states for, as example, a container ship model in an irregular sea state (Lee et al. 2006), or a very large floating structure for an irregular bidirectional sea state (Ikoma et al. 2000). Irregular wave results of drift forces are certainly useful; however they are not the best type of results to validate second order hydrodynamic theories and their numerical implementation. The aim of this experimental investigation is to obtain data of the slowly varying drift forces on a body of simple geometry appropriate for the validation of theoretical and numerical methods.

The tests were performed on a restrained body in monochromatic waves and bi-chromatic waves. An important part of the study is to access the depth effects on the slowly varying drift forces, so the tests were carried out for 3 different water depths: 40 cm and 55 cm which are considered to be of the shallow water type, and 3 m representing deep waters.
2. EXPERIMENTAL SETUP

The tested body is a vertical cylinder with rounded bottom. Figure 1 shows the curve that originates the wetted surface of the geometry by means of a 360° revolution. The cylinder radius $R$ is 0.325 m, the fillet radius $r$ is 0.1 m, and the draught $T$ is 0.2 m. The shallow water tests were carried out at the DHI shallow water basin, which includes an 18 meter wide segmented 3D piston type wave maker equipped with an active wave absorption system. The deep water tests were carried out on the DHI offshore basin, which has a water depth of 3 m. This basin is 20 m long and 30 m wide, and includes a hydraulic flap wave maker. The model was attached to a triangular shaped rig, which was fixed to the bottom of the basin in the case of the shallow water tests and fixed to a platform in the deep water basin (an image of this rig with the model attached can be seen in Figure 1). A 3D force transducer was placed between the rig and the model to measure the loads caused by wave-body interaction in $x$, $y$ and $z$ directions and wave gauges were placed in front and on the side of the model to measure the free surface elevation.

The waves selected for testing were chosen so that they would be in the relevant range of periods for the chosen geometry. Both monochromatic and bi-chromatic waves were tested. In the case of bi-chromatic waves, three different set of waves were chosen so that the difference between the harmonic frequencies ($\Delta w$) would be 0.5, 1.5 and 4.0 (rad/s).

3. RESTRAINED BODY EXPERIMENTAL RESULTS

The experimental time records were analyzed using a least squares based method by assuming that the force signal can be described by equation (1), and knowing beforehand the incident wave frequencies $w_1$ and $w_2$.

$$F(t) = F_1 \sin(w_1 t + \varphi_1) + F_2 \sin(w_2 t + \varphi_2) + F_3 \sin(2w_1 t + \varphi_3) + F_4 \sin(2w_2 t + \varphi_4) +$$

$$+ F_5 \sin(w_1 + w_2) t + \varphi_5 + F_6 \sin((w_2 - w_1) t + \varphi_6) + F_7$$

where $t$ is the time in seconds, and $F(t)$ is the force in Newton as a function of time. By fitting the signal to this equation using a least squares method one obtains the amplitudes ($F_i$) and phases ($\varphi_i$) of each component of the force. The first two terms, related to $F_1$ and $F_2$, are the so called linear forces which oscillate with the incident wave frequency. The last three terms are of the second order type and oscillate with the sum ($F_3$) or difference of frequencies ($F_4$) or are time independent (the steady drift force component $F_7$). An example of this fitting can be seen in Figure 2. The very good agreement between the numerical fitting and the experimental data is a good indication of the accurateness of the mathematical modelling of the physics involved in wave body interaction. The following graphs present the experimental harmonic amplitudes $F_i$, $i=1$ to $7$.

![Figure 1 Triangular rig with the model attached (left) and geometry of the body (right)](image)

![Figure 2 Time series plot of surge and heave force and numerical fitting](image)
Figure 3 shows the results for the linear surge and heave forces corresponding to the three waterdepths. They are presented as a function of the wave period and were non-dimensionalized by \( \rho \cdot g \cdot A \cdot L^2 \), where \( \rho \) is the fluid density, \( g \) is the gravitational acceleration, \( A \) is the incident wave amplitude, and \( L \) is a reference length which is assumed to be equal to 1 m. The results show that these forces are not very dependent of the water depth, since they have similar magnitudes in all plots. There seems to be a higher dispersion on the results for the 40 cm water depth than in the others, particularly for larger periods. This is probably related to the highly non linear profile of the incident waves which is typical of the shallow waters.

Figure 3 Linear wave exciting forces in surge and heave for monochromatic and bi-chromatic waves

Figure 4 Steady drift forces in surge and heave for monochromatic waves for the 3 water depths

Figure 5 Second order slowly varying drift force in surge and heave in bi-chromatic waves
The steady drift forces are plotted in Figure 4 as a function of the incident wave period T and is rendered non dimensional by \( \rho \cdot g \cdot A^2 \cdot L \). Each graph includes results for the three water depths. The heave forces increase significantly on restricted water depths, which can be confirmed by their amplification in the higher periods where the ratio between wavelength and water depth is high. This is also true for surge forces, although it is not so clear in the results.

The slowly varying drift force amplitudes are non-dimensionalized by \( 2 \cdot \rho \cdot g \cdot A_i \cdot A_j \cdot L \) where \( A_i \) is the amplitude of incident wave of period \( T_i \) and \( A_j \) is amplitude of the incident wave with period \( T_j \), with \( T_i < T_j \). They are plotted in Figure 5 as a function of the average period \( T \), where each graph corresponds to one frequency difference of the bi-chromatic waves. These forces are about one order of magnitude smaller than the corresponding linear forces, so the dispersion observed in the graphs is considered small. It is clear the increase in magnitude of the heave and surge forces with the water depth for higher periods. This behavior is consistent with the conclusions from previous studies published by the authors (Fonseca et al. 2008 and Pessoa et al. 2009). These results are very useful for the validation of these studies and for other researchers working with second order codes.

4. CONCLUSIONS

An experimental study on the wave exciting forces acting on a body of simple geometry has been presented. Both monochromatic waves and bi-chromatic waves were tested. A least squares based approach was used to analyse the experimental data by assuming that the wave exciting force can be decomposed in several components, namely linear forces, steady drift forces, slowly varying forces and forces oscillating with the sum of frequencies. The very good fitting of the numerical regression with the experimental data shows that the decomposition model is appropriate. Experimental results for 3 different water depths were obtained, and include linear forces, steady drift forces and second order forces accounting for the difference of frequencies resulting in 0.5, 1.5 and 4.0 rad/s. The results clearly show that the depth effect on the second order forces, be that steady or slowly varying, is stronger than in linear forces. These results provide a good validation tool for numerical and theoretical models.

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